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(54) **Breathing apparatus**

(57) Compressed-air breathing apparatus with a servo-controlled three-way valve 5 that admits air from a cylinder 1 to a face-mask 6 or releases air from the face-mask to the exterior under the control of a micro-processor control unit 4 responding to the pressure inside the facemask measured by a sensor 11.

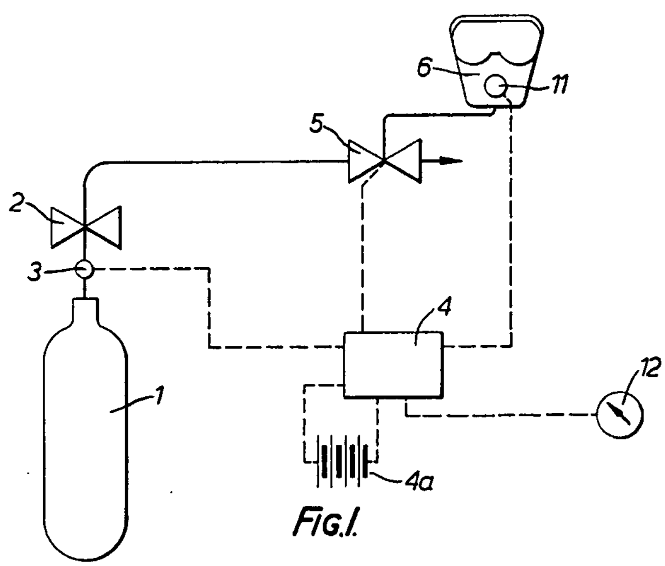

FIG.1

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The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

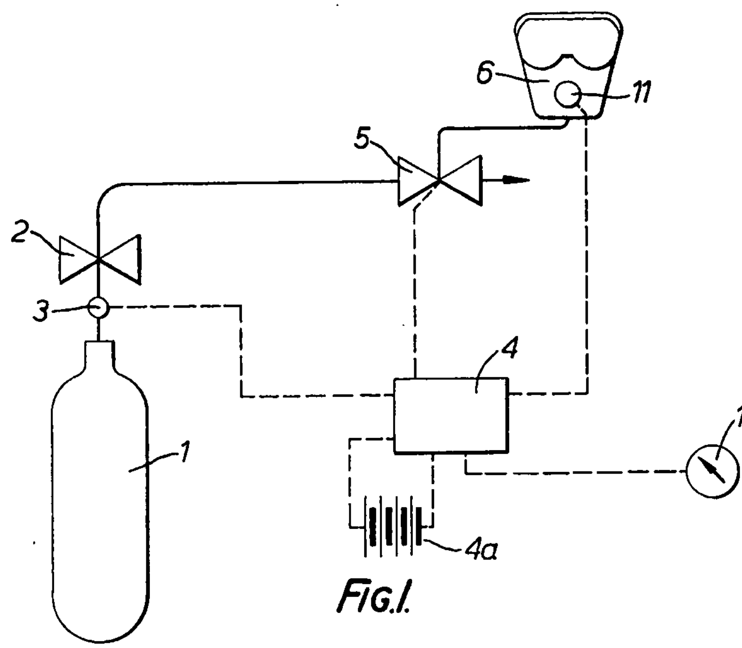

FIG.1.

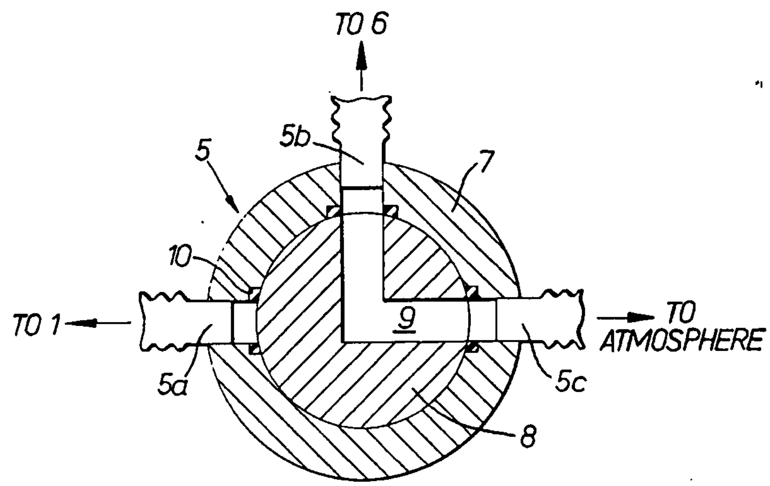

FIG.2.

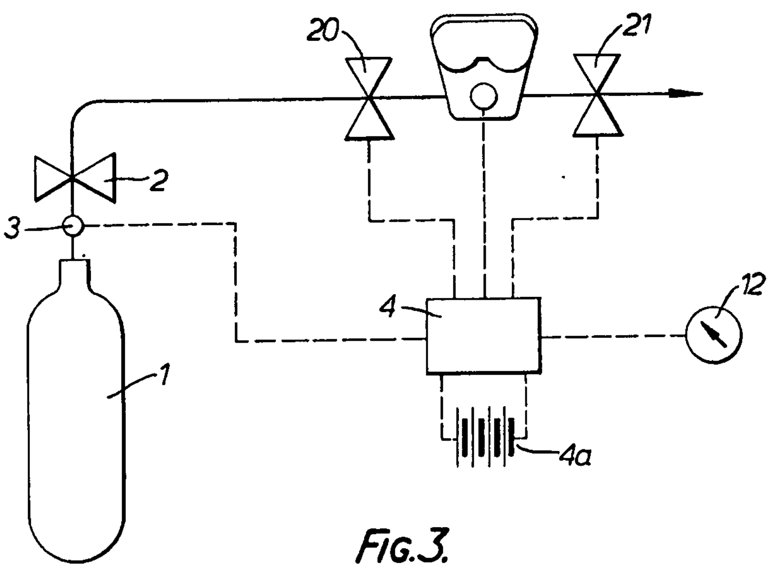

FIG.3.

SPECIFICATION

Improvements in and relating to breathing apparatus

The invention relates to breathing apparatus, and especially to compressed-air breathing apparatus which supplies air from a compressed-air cylinder carried by the user for breathing by the user, and allows air exhaled by the user to escape to the external environment.

The invention provides breathing apparatus comprising: means arranged in use to engage the face of a user and through which a life-supporting gas can be supplied for breathing by the user and through which gas exhaled by the user can escape; valve means for controlling the supply of life-supporting gas to the user and the escape of exhaled gas; gas supplying means communicating with an inlet to the valve means; means responsive to the pressure within the face-engaging means and arranged to give an output dependent upon that pressure; and a control unit arranged in use to actuate the valve means in response to the said output of the pressure-responsive means to allow life-supporting gas to be supplied to the user when the said pressure drops below a first predetermined value and to allow exhaled gas to escape when the said pressure rises above a second predetermined value that is higher than the first predetermined value.

The use of a single control unit controlling all of the flows of gas to and from a user makes it possible to obtain more precise and more consistent control of the operation of the apparatus than is possible with conventional breathing apparatus having an outlet valve for exhaled gas, the operation of which valve is independent of the supply of gas for breathing.

The life-supporting gas may be air, or oxygen-enriched air, or oxygen, or another oxygen-containing gas appropriate to the conditions under which the breathing apparatus is to be used.

The face-engaging means may comprise an orinasal mask through the interior of which in use life-supporting gas is supplied to the user and the gas exhaled by the user escapes; the valve means may then be arranged to control the supply of life-supporting gas to the user by controlling the supply to the interior of the orinasal mask and to control the escape of gas exhaled by the user by controlling the escape of gas from the interior of the orinasal mask; and the pressure to which the pressure-responsive means is responsive is preferably the pressure in the interior of the orinasal mask. The face-engaging means may also comprise a face-mask arranged in use to seal off from the exterior at least a region covering the eyes of the user and having a visor through which the user can see, and deflecting means arranged to cause life-supporting gas to pass over the inside of the visor before entering the orinasal mask and to cause gas exhaled by the user to escape to the valve means without passing through the interior of the outer mask. The face-mask may entirely surround the orinasal mask and include a duct arranged to convey the gas exhaled by the user from the interior of the orinasal mask to the exterior of the face-mask. Instead, the face-engaging means may comprise a face-mask covering the mouth, nose, and eyes of the user without an inner orinasal mask.

The gas-supplying means may comprise means arranged in use to be connected to a cylinder or other container of compressed gas and to convey the contents of the cylinder to the valve means. When the valve means is mounted on a face-mask or otherwise secured to the user's head, which is in some respects preferable as it reduces the volume of gas on the user's side of the valve means, and the gas is supplied from a container on the user's back, the gas-supplying means advantageously comprises a pair of flexible hoses, one passing over each shoulder of the user, in order that the forces acting on the valve-means as a result of gas pressure in the flexible hoses shall to some extent balance each other.

The apparatus may comprise a non-return valve arranged to prevent a surrounding medium from flowing to the user when the valve means is in the condition permitting gas exhaled by the user to escape.

The valve means advantageously comprises a valve body having respective ports through which life-supporting gas can be admitted from the gas-supplying means, through which gas can flow to and from the face-engaging means, and through which exhaled gas can escape, and a valve member movable between a position in which life-supporting gas can be supplied from the gas-supplying means to the face-engaging means, a position in which gas can escape from the face-engaging means through the valve means, and a position in which life-supporting gas cannot be so supplied and in which gas cannot so escape. That makes possible an outstandingly robust and reliable valve construction, because there need be in effect only one moving part, without sacrificing the other advantages that can be obtained with apparatus according to the present invention. The valve member advantageously defines a passageway within the volume swept out by it as it moves in operation, which passageway in the first two said positions of the valve member connects appropriate ones of the said ports to permit the respective flows of gas, and in the third said position does not connect any two said ports.

There may be three said ports through one of which in operation gas flows both to and

from the user, and the port through which life-supporting gas can be admitted to the valve and the port through which gas can escape from the valve are then advantageously positioned on either side of the port through which gas can flow to and from the user. This is especially advantageous when combined with the features mentioned in the latter part of the last paragraph.

The valve member is advantageously arranged in operation to rotate about an axis between its different operative positions. If, as is preferred, the valve member is basically a solid of revolution about the said axis then the need to provide extra space within which the valve member can move is avoided. If there are only three ports as mentioned above, then preferably they are spaced apart circumferentially by arcs subtending at the said axis angles substantially different from 120°, and the ends of the said passageway are spaced apart circumferentially by an arc substantially equal to that between the port through which gas can flow to and from the user and either of the other two ports. That allows a construction of the valve means such that in normal operation there is no position of the valve member in which the port through which life-supporting gas can be admitted is in direct communication through the valve means with the port through which gas can escape. Such a construction is preferred because it greatly reduces the risk that a malfunction of the control unit could result in the user's store of life-supporting gas being allowed to escape to the exterior. Advantageously, the port through which life-supporting gas can be admitted to the valve and the port through which gas can escape from the valve are substantially 90° away from the port through which gas can flow to and from the user.

The valve means may instead comprise a first valve having a valve body with a port through which life-supporting gas can be admitted from the gas-supplying means and a port through which gas can flow to the face-engaging means, and a valve member movable between a position in which life-supporting gas can be supplied from the gas supplying means to the face-engaging means and a position in which life-supporting gas cannot be so supplied, and a second valve having a valve body with a port through which gas can flow from the face-engaging means and a port through which exhaled gas can escape, and a valve member movable between a position in which gas can escape from the face-engaging means through the second valve and a position in which gas cannot so escape.

The control means may be arranged to emit electrical signals to actuate the valve means, which then preferably includes means for producing, in response to the signals from the control means, mechanical movements that effect the changes in the condition of the valve means. The means for producing mechanical movements may be an electric motor, for example, a stepper motor or servomotor, or may be a a solenoid. Having the valve means actuated electrically is especially advantageous if a very complex or versatile pattern of control is required, for example, responding to other inputs in addition to the output of the pressure-responsive means. In these cases the control unit is advantageously a microprocessor, which has the further advantage that it can be specially programmed, or even made reprogrammable, to give the different patterns of control required for different uses of the apparatus, or to accord with local practice in different places. The pressure responsive means may be a piezoelectric transducer, especially if the control unit comprises a microprocessor or other electrical device.

Advantageously, there is provided a member that can be manipulated by the user to produce the said mechanical movements independently of the aforesaid means for producing mechanical movements. The user may then be able to maintain the operation of the apparatus manually in the event of a malfunction of the control unit or a failure of the electrical power supply, albeit on a lower level of performance.

The apparatus advantageously comprises an information readout, and the control unit may then cause the readout to display information concerning the operation of the apparatus. The control unit may be arranged to respond to malfunctions of the apparatus and to cause the readout, if there is one, to display a signal indicating a malfunction, or to cause means for generating sound to emit a sound indicating a malfunction, or otherwise to cause the malfunction to be indicated to the user of the apparatus or of other persons who may be in a position to intervene. The apparatus may comprise further pressure-responsive means responsive to the pressure at a point within the gas-supplying means and arranged to give an output dependent upon that pressure, and the control means may be arranged to cause an indication to be given when that pressure falls below a predetermined value. The further pressure-responsive means may be mounted in a component arranged to engage with the mouth of a cylinder or like container of compressed gas, and arranged to respond to the pressure in the container.

Two forms of breathing apparatus constructed in accordance with the invention will now be described by way of example only with reference to the accompanying drawings, in which:

Fig. 1 is a diagram of the first form of apparatus;

Fig. 2 is a schematic cross-sectional view of a valve forming part of the apparatus shown in Fig. 1; and

Fig. 3 is a diagram of the second form of apparatus.

Referring to the accompanying drawings, the first form of apparatus comprises a cylinder 1 containing compressed life-supporting gas arranged to be carried on the back of a user by means of a harness (not shown) which may be of conventional design. At the mouth of the cylinder 1 is mounted a cylinder-head valve assembly 2 which may comprise, for example, a manually operable shut-off valve fixed to the cylinder 1 and a pressure-reducing device forming a permanent part of the apparatus separably connected to the shut-off valve.

A pressure sensor 3 is mounted in the valve assembly 2 upstream of any pressure reducing device so that when the shut-off valve is open the pressure sensor is exposed to substantially the full pressure of gas in the cylinder 1. The pressure sensor 3 is a piezoelectric transducer which emits an electrical signal that is fed to a control unit 4. The control unit 4 is a microprocessor-based device which is supplied with electric power, both for its own operation and for the various functions that it controls, by a rechargeable accumulator 4*a* carried by the user.

The gas outlet from the valve assembly 2 is connected to one port 5*a* of a three-way valve 5 by a pipe or hose which forms, with those parts of the valve assembly 2 that are permanent parts of the apparatus, means for supplying life-supporting gas from the cylinder 1 to the three-way valve.

A second port 5*b* of the three-way valve 5 communicates with a mask 6. The mask 6 comprises an outer facemask having a visor through which the user can see and an inner, orinasal, mask entirely surrounded by the facemask. The mask 6 is so provided with deflecting means (not shown) which may include non-return valves, baffles, and the like, that at least part of the gas entering the mask from the three-way valve 5 as the user inhales passes over the inside of the visor before entering the orinasal mask but that gas exhaled by the user returns from the orinasal mask to the three-way valve through a duct provided for the purpose without passing through the interior of the outer facemask. A piezoelectric transducer 11 senses the pressure in the interior of the orinasal mask and emits an electrical signal that is fed to the control unit 4.

The third port 5*c* of the three-way valve 5 communicates with the external environment, to allow gas exhaled by a user to escape. A non-return valve (not shown) is provided to allow gas to escape from the apparatus but to prevent a surrounding medium, which may be a gaseous or, if, for example, the apparatus is being used underwater, liquid, medium from entering the apparatus.

As may be seen from Fig. 2, the three-way valve 5 is a simple rotary valve, having a hollow cylindrical valve body 7 and a rotatable cylindrical valve member 8 occupying the central cavity of the valve body. Each of the ports 5*a*, 5*b*, and 5*c* passes through the valve body 7, and is encircled at its inner end by an O-ring 10 sealing the valve body against the valve member 8. Each port 5*a*, 5*b*, or 5*c* is thus sealed off unless it is aligned with an opening in the valve member 8. The ports 5*a* and 5*c* are diametrically opposite one another, and the port 5*b* is 90° away from both of them, as seen from the central axis of rotation of the valve member 8. The valve member 8 has a single passage 9 through it, the ends of which open out through the surface of the valve member 90° apart.

Thus the passage 9 can connect together the ports 5*b* and 5*c*, as is shown in Fig. 2, allowing gas to escape from the mask 6 to the exterior. If the valve member 8 is rotated 90° anticlockwise as seen in Fig. 2, the passage 9 will connect the ports 5*a* and 5*b*, allowing gas from the cylinder 1 to be supplied to the mask 6. If the valve member 8 is slightly displaced from either of those positions, then the flow of gas will be reduced because there will be a constriction where the passage 9 meets the ports. If the valve member 8 is far enough from either of those positions then all three of the ports 5*a*, 5*b*, and 5c will be sealed off and the valve 5 will be closed. There is no position of the valve member 8 in which the ports 5*a* and 5*c* are open simultaneously, so that it is impossible to exhaust the gas from the cylinder 1 directly to the exterior merely by rotating the valve member to an incorrect position. The valve member 8 is rotated in normal operation by an electric servomotor (not shown) controlled by the control unit and powered by the accumulator 4*a*.

If a position 45° anticlockwise from that shown in Fig. 2 is used as the closed position of the valve 5. Then all of its operative positions can be reached with a rotation of only 90° and, especially in this case, a reciprocating rather than a rotary actuator may be used. The actuator may then be a solenoid instead of a servomotor.

A wheel (not shown) is secured to one axial end of the valve member 8 and is so arranged that it can be rotated by the user to operate the valve 5 independently of the servomotor if, for example, the control unit 4 malfunctions or the power supply fails. Depending on the arrangement of the valve, a lever or other manipulable member may be provided instead. The wheel or other member may be covered by a protective cap when not being used.

The three-way valve 5 and its servomotor are mounted on the mask 6 to minimise the volume of gas between the port 5*b* and the user's lungs. The port 5*a* is connected to the valve assembly 2 *via* a pair of flexible pres-

sure-hoses, one of which passes over each shoulder of the user, arranged so that the forces exerted on the user's head as a result of the gas pressure in the hoses largely cancel out. The three-way valve may instead be mounted on the user's body, in order to reduce the weight of the mask 6. The three-way valve 5 is then advantageously replaced by a four-port valve with separate ports and hoses for gas passing to and from the mask 6.

A readout 12, controlled by the control unit 4, is mounted at a convenient point on the apparatus, for example, on a carrying strap passing over the user's chest. The control unit, in operation, causes the readout to display information about the state of the apparatus, such as the gas pressure in the cylinder 1 as sensed by the piezoelectric transducer 3. The control unit 4 is also arranged to respond to malfunctions of the apparatus by displaying an appropriate warning on the readout, and by causing a sound-generator (not shown) to emit an audible warning. A warning is also given when the gas pressure in the cylinder 1 drops below a certain level, indicating that the gas supply is about to run out.

In operation, gas from the compressed-gas cylinder 1 is supplied through the cylinder-head valve assembly 2 to the first port 5*a* of the three-way valve 5. When the user of the apparatus begins to inhale, the pressure in the orinasal mask drops. The pressure sensor 11 signals this drop to the control unit 4, which actuates the servomotor to rotate the valve member 8 to connect the ports 5*a* and 5*b*, thus supplying the user with life-supporting gas to inhale. If there is a failure anywhere in the gas supply system, so that the user is not supplied with gas, or is not supplied with enough gas, the pressure in the orinasal mask will continue to drop, and the control unit 4 is arranged to give a warning signal at the readout 12 if the pressure drops too low. For an ordinary positive-pressure breathing apparatus, the control unit 4 might be set to supply gas to the mask from the cylinder 1 when the mask pressure drops below, say, 400 Pa above ambient pressure and to give a warning signal at perhaps 250 Pa. When the user stops inhaling, the mask pressure will rise above the threshold set, and the control unit 4 then closes the valve 5. When the user begins to exhale, the mask pressure rises above a second threshold of, say, 600 Pa above ambient pressure, and the control unit 4 then rotates the valve member 8 to connect the ports 5b and 5*c*, enabling the gas exhaled by the user to escape. If the gas outlet is obstructed or the nonreturn valve jams, the pressure in the orinasal mask will continue to rise, and the control unit causes a warning to be displayed at the readout 12 if the mask pressure rises above, say, 700 Pa.

Referring now to Fig. 3 of the drawings, the second form of apparatus is the same as the first form except that the three-way valve 5 is replaced by a pair of valves 20 and 21. Parts of the apparatus that are the same in the two forms of apparatus shown have been accorded the same reference numerals in Fig. 3 as in Fig. 1, and the description of them will not be repeated.

The pipe or hose from the cylinder-head valve assembly 2 is connected to one side of the valve 20, the other side of which is in communication with the interior of the mask 6 which, as mentioned above, is so arranged that at least part of the gas entering the mask from the valve 20 passes over the inside of the visor before entering the orinasal mask. One side of the valve 21 is in communication with the interior of the orinasal mask and the other side with the external environment. A non-return valve (not shown) may be provided as in the first form of apparatus. Both valves 20 and 21 are provided with actuators, which are controlled by the control unit 4. The valves 20 and 21 may be mounted on the body of the wearer and connected to the mask 6 by flexible tubes, or if they and their actuators are light enough they may be mounted directly on the mask.

The valves 20 and 21 may be any suitable form of valve, and the actuators may be any suitable electrically-controlled actuators appropriate to the form of valve being used, for example, solenoids or servo-motors.

The operation of the second form of valve is similar to that of the first form, with the control unit 4 causing the valve 20 to be opened to permit gas to enter the mask 6 when the user inhales, and causing the valve 21 to be opened to permit gas to escape from the mask 6 when the user exhales.

CLAIMS

1. Breathing apparatus comprising: means arranged in use to engage the face of a user and through which a life-supporting gas can be supplied for breathing by the user and through which gas exhaled by the user can escape; valve means for controlling the supply of life-supporting gas to the user and the escape of exhaled gas; gas supplying means communicating with an inlet to the valve means; means responsive to the pressure within the face-engaging means and arranged to give an output dependent upon that pressure; and a control unit arranged in use to actuate the valve means in response to the said output of the pressure-responsive means to allow life-supporting gas to be supplied to the user when the said pressure drops below a first determined value and to allow exhaled gas to escape when the said pressure rises above a second predetermined value that is higher than the first predetermined value.

2. Apparatus as claimed in claim 1, wherein: the face-engaging means comprises

an orinasal mask through the interior of which in use life-supporting gas is supplied to the user and the gas exhaled by the user escapes; the valve means is arranged to control the supply of life-supporting gas to the user by controlling the supply to the interior of the orinasal mask and to control the escape of gas exhaled by the user by controlling the escape of gas from the interior of the orinasal mask; and the pressure to which the pressure-responsive means is responsive is the pressure in the interior of the orinasal mask.

3. Apparatus as claimed in claim 2, wherein the face-engaging means comprises a face-mask arranged in use to seal off from the exterior at least a region covering the eyes of the user and having a visor through which the user can see, and deflecting means arranged to cause life-supporting gas to pass over the inside of the visor before entering the orinasal mask and to cause gas exhaled by the user to escape to the valve means without passing through the interior of the outer mask.

4. Apparatus as claimed in claim 3, wherein the face-mask entirely surrounds the orinasal mask and includes a duct arranged to convey the gas exhaled by the user from the interior of the orinasal mask to the exterior of the face-mask.

5. Apparatus as claimed in any one of claims 1 to 4, wherein the gas-supplying means comprises means arranged in use to be connected to a cylinder or other container of compressed gas and to convey the contents of the cylinder to the valve means.

6. Apparatus as claimed in claim 5, which comprises a non-return valve arranged to prevent a surrounding medium from flowing to the user when the valve means is in the condition permitting gas exhaled by the user to escape.

7. Apparatus as claimed in any one of claims 1 to 6, wherein the valve means comprises a valve body having respective ports through which life-supporting gas can be admitted from the gas-supplying means, through which gas can flow to and from the face-engaging means, and through which exhaled gas can escape, and a valve member movable between a position in which life-supporting gas can be supplied from the gassupplying means to the face-engaging means, a position in which gas can escape from the face-engaging means through the valve means, and a position in which lifesupporting gas cannot be so supplied and in which gas cannot so escape.

8. Apparatus as claimed in claim 7, wherein the valve member defines a passageway within the volume swept out by it as it moves in operation, which passageway in the first two said positions of the valve member connects appropriate ones of the said ports to permit the respective flows of gas, and in the third said position does not connect any two said ports.

9. Apparatus as claimed in claim 7 or claim 8, wherein there are three said ports through one of which in operation gas flows both to and from the user.

10. Apparatus as claimed in claim 9 when dependent upon claim 8, wherein the port through which life-supporting gas can be admitted to the valve and the port through which gas can escape from the valve are symmetrically positioned on either side of the port through which gas can flow to and from the user.

11. Apparatus as claimed in any one of claims 7 to 10, wherein the valve member is arranged in operation to rotate about an axis between its different operative positions 12. Apparatus as claimed in claim 11 when dependent upon claim 10, wherein the three ports are spaced apart circumferentially by arcs subtending at the said axis angles substantially different from 120°, and the ends of the said passageway are spaced apart circumferentially by an arc substantially equal to that between the port through which gas can flow to and from the user and either of the other two ports.

13. Apparatus as claimed in any one of claims 7 to 12, wherein the construction of the valve means is such that in normal operation there is no position of the valve member in which the port through which life-supporting gas can be admitted is in direct communication through the valve means with the port through which gas can escape.

14. Apparatus as claimed in claim 13 when dependent upon claim 12, wherein the port through which life-supporting gas can be admitted to the valve and the port through which gas can escape from the valve are substantially 90° away from the port through which gas can flow to and from the user.

15. Apparatus as claimed in any one of claims 1 to 6, wherein the valve means comprises a first valve having a valve body with a port through which life-supporting gas can be admitted from the gas-supplying means and a port through which gas can flow to the face-engaging means, and a valve member movable between a position in which life-supporting gas can be supplied from the gas supplying means to the face-engaging means and a position in which life-supporting gas cannot be so supplied, and a second valve having a valve body with a port through which gas can flow from the face-engaging means and a port through which exhaled gas can excape, and a valve member movable between a position in which gas can escape from the face-escaping means through the second valve and a position in which gas cannot so escape.

16. Apparatus as claimed in any one of claims 1 to 15, wherein the control means is arranged to emit electrical signals to actuate the valve means, and the valve means in-

cludes means for producing, in response to the signals from the control means, mechanical movements that effect the changes in the condition of the valve means.

17. Apparatus as claimed in claim 16, wherein the means for producing mechanical movements is one or more electric motors.

18. Apparatus as claimed in claim 16, wherein the means for producing mechanical movements is one or more solenoids.

19. Apparatus as claimed in any one of claims 16 to 18, wherein there is provided at least one member that can be manipulated by the user to produce at least some of the said mechanical movements independently of the aforesaid means for producing mechanical movements.

20. Apparatus as claimed in any one of claims 1 to 19, wherein the pressure-responsive means comprises a piezoelectric transducer.

21. Apparatus as claimed in any one of claims 1 to 20, which comprises an information readout and wherein in operation the control unit causes the readout to display information concerning the operation of the apparatus.

22. Apparatus as claimed in claim 21, wherein the control unit is arranged to respond to malfunctions of the apparatus and to cause the readout to display a signal indicating a malfunction.

23. Apparatus as claimed in any one of claims 1 to 22, which comprises means for generating sound and wherein the control unit is arranged to respond to malfunctions of the apparatus and to cause the sound generating means to emit a sound indicating a malfunction.

24. Apparatus as claimed in any one of claims 1 to 23, which comprises further pressure-responsive means responsive to the pressure at a point within the gas-supplying means and arranged to give an output dependent upon that pressure, and wherein the control means is arranged to cause an indication to be given when that pressure falls below a predetermined value.

25. Apparatus as claimed in any one of claims 1 to 24, wherein the control unit comprises a microprocessor.

26. Breathing apparatus substantially as hereinbefore described with reference to, and as shown in, the accompanying drawings.

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